EVALUATION, PRACTICE AND REMARKS ON THE IEC 61000-3-2 STANDARD

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Abstract - This paper describes an evaluation, interpretation and discussion of the IEC61000-3-2 standard [1]. Since January 2001, this standard is applied. Some of the directives mentioned in this reference are liable to interpretations, test conditions are not well defined and warm up conditions are neglected (except for lamps). In practice, a lot of single phase [2] as well as three phase non linear loads do not comply with the standard. All tested devices show bad power quality parameters. Using an IEC full compliant programmable power source and power analyzer, several test set ups are analyzed, with respect to the IEC61000-3-2 standard.
The paper presents some important remarks and conclusions, based on measurements on several single phase non linear loads.

I. INTRODUCTION

Nowadays both variable speed drives and IT-equipment, such as monitors, PC's, printers, faxes are widely spread. These apparatus have a non-linear behavior: they produce harmonic currents due to the high peak currents [2,3,4,5].
In this paper comprehensive measurements are discussed in order to analyse the harmonic contents of non linear load currents and their influencing parameters. For different set ups and load conditions, both currents and voltages are measured and compared to the operating ranges of the standard [1]. Finally, evaluations are made on the measurement conditions as mentioned in the standard.

II. TEST CONFIGURATION

Using a programmable power source, a sinusoidal voltage with rms-value of 230 V is generated on each phase (Figure 1).
Taking the voltage signal on phase U as reference, the voltage signals on phase V and W are lagging with respectively 120° and 240°.
Measurements of phase and neutral conductor currents are done using a high performance power analyzer [6].

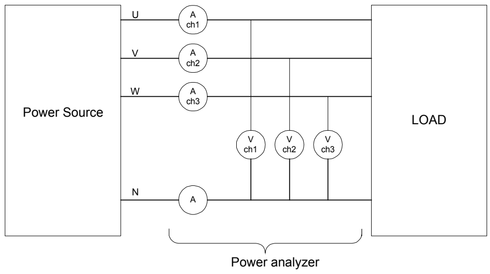


Figure 1 Measurement set-up

III. ANALYSIS OF THE LOAD CURRENT

I.1 Measurements on different monitors and PC's

In order to determine the current waveform of IT equipment, 19 monitors and 9 PC's were tested. All monitors and PC's show similar current fingerprints (Figure 2). This can be explained by the similar topology of the switching power supply of the devices.

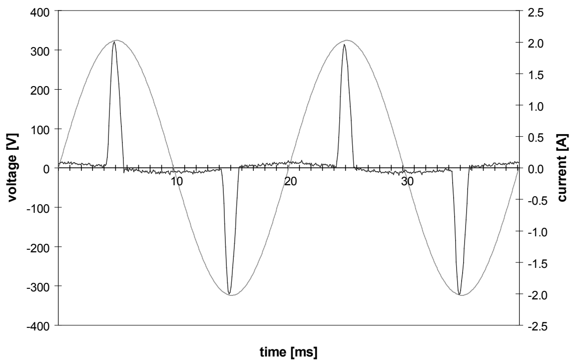
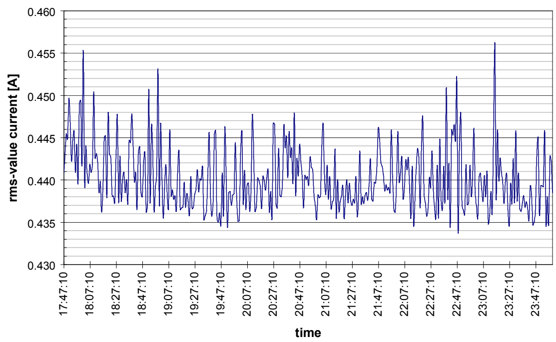


Figure 2 Current and corresponding voltage of a monitor. The current fingerprint is typical for all tested monitors and PC's.

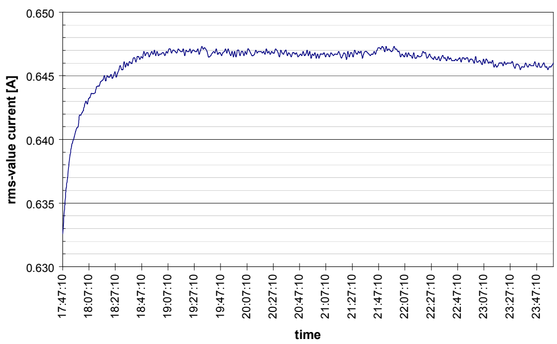
Taking into account the long stabilizing period of some apparatuses (Figure 3.b), most measurements were performed at least 1,5 h after switching on the apparatus.

III.1.1 Stabilizing period

The stabilizing period for the equipment under test is not determined by the standard, except for lamps which require a warming up time of 15 minutes after an ageing of at least 100h. Warming up times for all other types of equipment are neglected in the standard. Figure 3 shows two graphs representing the rms-current vs. time for two different monitors from start up to steady state. There are high differences between the monitors concerning the warming up period and the stability of the current. In general most monitors and PC's need a long warming up period (up to 90 minutes, e.g. monitor (b) in Figure 3), some are already stabilized after 15 minutes.
These remarks are already reported to the IEC/SC77A [7].



monitor (a)



monitor (b)

Figure 3 Rms-current vs. time for two different monitors. The initial time corresponds to the moment of switching on the monitor.

III.1.2 Standard Tests

When we compare the harmonic currents with the class D limits of the standard IEC61000-3-2 [1], we see that, for all tested apparatuses, the harmonics with order less than 19 exceed the limits. Figure 4 shows the harmonic spectrum of a monitor, together with the class D limits of the standard.
The standard doesn't mention any limitation concerning loads less than 75W, so monitors and PC's don't have to comply with this reference. However, every PC has his monitor, so both equipment can be considered as one single load. In this case the load power does exceed the 75W limit and normative limitations have to be respected.

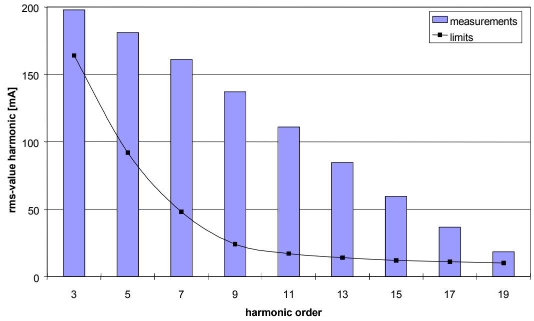


Figure 4 Harmonic spectrum of a monitor. The class D limits of the standard IEC61000-3-2 are also shown.

I.2 Analysis of the voltage source influence

III.1.3 Voltage distortion limits

The requirements of the voltage at terminals of the EUT are well described in a limitation for each harmonic. However, there is nothing mentioned about source impedance and phase angle of the harmonics.
During the measurements, voltage is changed in harmonic spectrum (both amplitude and angle) with respect to the conditions as mentioned by the norm. A second point of view was the analysis of the influence of the source impedance. Both minimum source impedance and flicker impedance (as mentioned in [8]) were applied. Nevertheless, a great influence in harmonic contents is found especially for the higher order harmonics. However all tests were performed with a test voltage with respect to the standard. Measurement results corresponding with the voltages and impedances of Table I and Table II, are shown in the graphs of Figure 5 for a load with capacitive input and bridge rectifier, which is the worst case type of non linear loads.

Table I: Set-ups in voltage, with respect to the norm (V_{rms} = 230 V)

Voltage	harmonic contents
V_1	Sine wave
V_2	V_3 = 0,80%, ϕ_3 = 0° V_5 = 0,30%, ϕ_5 = 180° V_7 = 0,20%, ϕ_7 = 180° V_9 = 0,10%, ϕ_9 = 180° V_{11} = 0,05%, ϕ_{11} = 0°
V_3	V_3 = 0,80%, ϕ_3 = 180° V_5 = 0,30%, ϕ_5 = 180° V_7 = 0,20%, ϕ_7 = 180° V_9 = 0,10%, ϕ_9 = 180° V_{11} = 0,05%, ϕ_{11} = 180°

Table II: Used source impedances

Impedance 1: Minimum source impedance	R = 4 mΩ, L = 135µH
Impedance 2 : Flicker impedance	R = 240 mΩ, L = 477µH

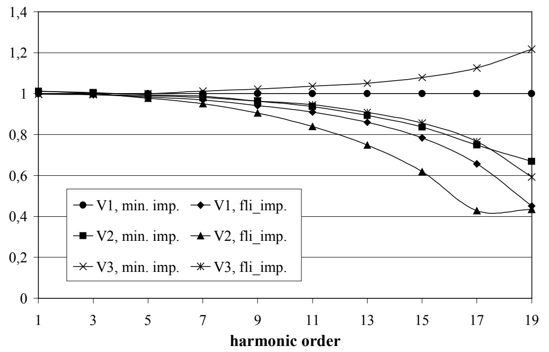


Figure 5 Influence of harmonic spectrum of testing voltage and source impedance during compliance test with respect to standard requirements for supply voltages and impedances of Table I and Table II.

The standard doesn't mention anything concerning the source impedance as long as the voltage at terminals of the EUT is compliant. However, this is not sufficient to guarantee the repeatability. E.g. according to the IEC61000-3-2 standard, harmonics are neglectable when smaller than 5 mA or when smaller than 0,2% of Irms. Repeatability is assumed when variations are within 5%. However for different supply voltages and source impedances, Figure 5 shows variations up to 55% for the 19th harmonic in a current range that is not neglectable.

I.3 Influence of more single phase loads

The influence of the number of PC's on the electrical and power quality parameters was analyzed. A higher number decreases the current crest factor and the total harmonic distortion and increases the power factor. This is due to the broadening of the peak signal in case of a higher number of PC's, as illustrated in Figure 6.

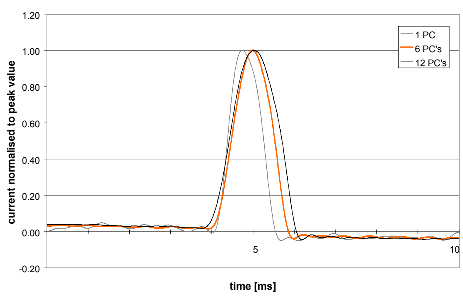


Figure 6 Influence of the number of PC's on the current wave form supplied from a full compliance power source

One of the major reasons for this broadening is the grid impedance and accordingly the variation of the supply voltage with the load. Consequently, the current waveform doesn't multiply linearly with the number of PC's. Further analysis of higher order harmonics were done.
The attenuation factors for most harmonics, as mentioned in [9] and given in (1), will decrease for an increasing number of non linear loads in reference to a situation with a single load. (Figure 7). However, especially in case of power supply from the public distribution network, the attenuation factor of some higher order harmonics can increase up to 130% (cfr. 17th harmonic of Figure 7). Explanation can be found in the high influence of higher order voltage harmonics on harmonic currents [5].

$$AF_h = \frac{I_h^N}{N.I_h^1} \tag{1}$$

where:

I_h^N : Resultant current for harmonic h for N units operating in parallel

I_h^1 : Current for harmonic h when N = 1

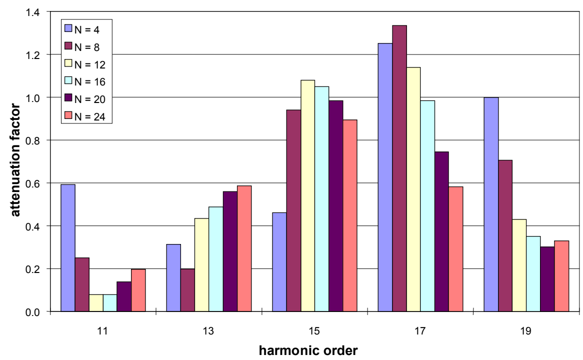


Figure 7 Attenuation factors for higher order harmonic currents supplied from public distribution network.

IV. CONSIDERATIONS ABOUT THE CLASS D

Equipment shall be deemed to class D if the current wave shape of each half period is within the envelope and fulfils the conditions given in [1]. Harmonic current limits for class D are given in table III.
The power limitation for class D equipment is 600W, due to the limits of the 15th and higher order harmonics of class A limitation. However, with the given voltage and a displacement power factor equal 1 (normal value approx. 0.95), the power rating is 580W.
On the other hand, with respect to de D class envelope, and the limits given in table III, we will find a great discrepancy in harmonic limits.

Table III: Harmonic current limits for class D

Harmonic order	Maximum harmonic current [mA/W]	Maximum permissible harmonic current [A]
3	3,4	2,30
5	1,9	1,14
7	1,0	0,77
9	0,5	0,4
11	0,35	0,33
13	3,85/n	0,21
$15 \leq n \leq 39$ (odd only)	3,85/n	0,15 * (15/n)

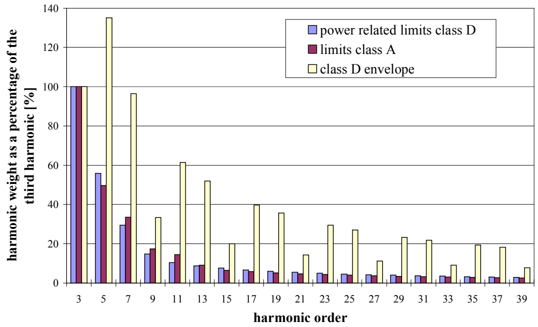


Figure 8 Harmonic limits for class D, class A and harmonic contents of the D envelope, referred to 3th harmonic

Related to the third order harmonic, the results given in Figure 8 are quite similar for class A and class D. This means that the class D limitation is not more strictly than the class A limitation. On the other hand, referring to the D envelope, the harmonic spectrum is much higher than the limitations given by the class itself, caused by a low value of the 3th harmonic.

V. MISCELLANEOUS CONSIDERATIONS

All class D equipment consuming a power less than 75W do not have to comply with the standard, however a great number of this equipment will have a harmonic spectrum much higher than the limitations as mentioned in the standard. Amendment 14 of the standard includes only TV's, PC's and monitors for class D limitations. All the rest becomes class A, with less severe limitations (class A is not power related).

The power consumption of printers is strongly affected by the task of the printer (loading paper, printing). There are no requirements or advising parameters concerning the correct application of the standard.

Another problem is caused by copiers. During the copy proces the highlighting of the lamp generates a sine wave current. The rest of the copy time there is a strong distortion of the current. A similar effect is found for fax apparatuses where a sinewave only appears when receiving messages (Figure 9). Due to this sine wave current and his duration, copiers and faxes will meet the requirements of class A equipment, where the harmonic current emission limits are within a wide range.

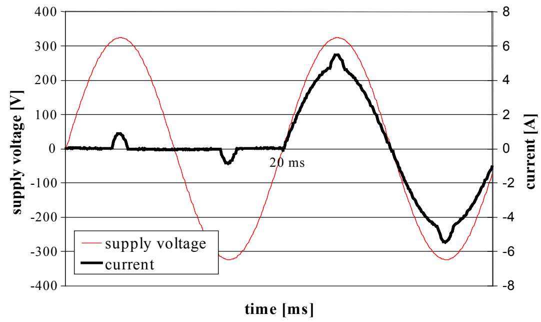


Figure 9 Voltage and current waveform of a fax apparatus when receiving at 20 ms.

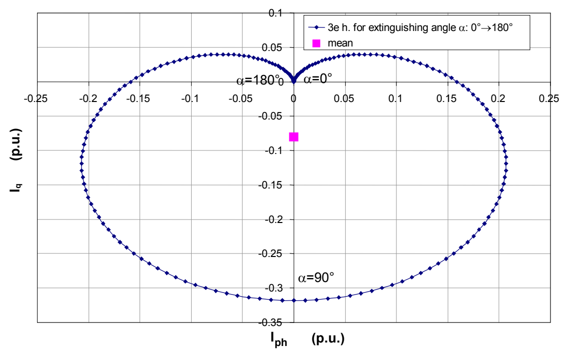
The standard doesn't mention anything about the use of the limits for steady state or transitory state in function of the kind of apparatus.

Only for lamps a working time of 100 hours is required before tests may be done. Other equipment such as CRT, TV's, Monitors…, don't have to meet this requirement.

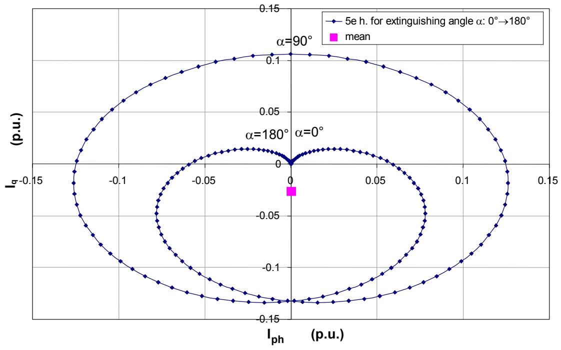
As mentioned before, the warming up time of monitors (up to 90 minutes) and printers (up to 30 minutes) is not required. Only lighting equipment will need a warming up time of 15 minutes (what will be enough).

Concerning professional equipment, there is no directive for limitation of harmonic current emission except for welding machines, which have to meet the requirements of the IEC61000-3-4 directive.

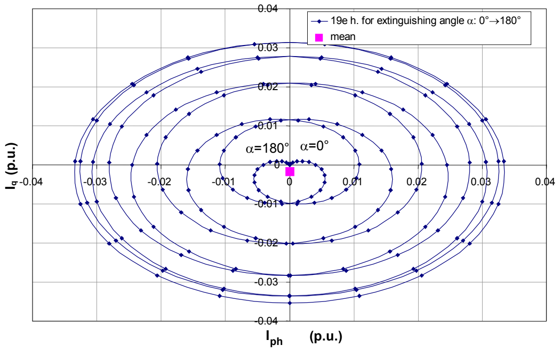
Dimming devices with a power consumption less than 1000W are excluded of the standard, however the emission of harmonic currents may exceed the limits of the standard. Figure 10 shows the 3th (a), the 5th (b) and the 19th (c) harmonic in phase and quadratic current components referred to the current amplitude of the uncutted current waveform.



(Fig. 10a)



(Fig. 10b)



(Fig. 10c)

Figure 10 Current component in phase and in quadrature with sinusoidal supply voltage for extinguishing angle α of the dimmer: 0° → 180° (referred to the current amplitude of the uncut current waveform).

However, it can be stated that dimmers are excluded from the standard because of the mutual compensation between the high number of dimmers on the grid. The dimmers on the grid are steered with different firing or extinguishing angles and consequently, the mean of all harmonics remains nearly zero (Figure 10 (a), (b) and (c)). Only a relatively small mean current component in phase is found, representing the losses.

VI. CONCLUSIONS

The warm up time for different equipment was analyzed. Current variations of more than 5% between cold and warm state, are found. Consequently, the warm up time should be a very relevant parameter for a good determination of the EUT and not only for lamps. A minimum warm up time for all types of equipment (except hand held) of minimum 30 minutes should be considered.
In amendment 14 of the standard all apparatus within the special wave shape of class D are considered as class A. Only TV's, PC's and monitors belong to class D, which means an advantage for the manufacturing industries, but not for the power quality of the supply system.
A great variation in the amplitude of the higher harmonics exists (from +20% to –60%), caused by small voltage harmonics (in supply voltage or caused by voltage drops). Consequently, the results gathered by an IEC compliance test can have a huge variation and may be not sufficient to comply to the repeatability conditions. For this problem, a better and rigorous description of voltage parameters and a definition of the source impedance (e.g. flicker impedance) are needed. On the basis of these results, the IEC SC77A-TF2 is already working on this item.
There is a great interpretation gap in the standard, so manufacturers of equipment who has to meet the requirements of the standard IEC61000-3-2 can use these gaps to comply with the reference. For lighting equipment with a power consumption less than 25W, the EUT has to meet the power related requirements of class D, or a special current requirement. There is no need to comply both requirements.

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REFERENCES

[1] IEC61000-3-2, "*Electromagnetic compatibility (EMC) – Part 3-2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)",* 2000.

[2] S. Faβbinder, "*EN61000-3-2 und die praxis*", etz Elektrotechniek Heft20/2000, pp. 2-5.

[3] A.-C. Liew, "Excessive neutral currents in three-phase fluorescent lighting circuits", *IEEE Transactions on Industry Applications*, Vol. 25, No. 4, July/August 1989, pp. 776-782.

[4] J. Desmet, I. Sweertvaegher, G. Vanalme and R. Belmans, "Analysis of electrical and power quality parameters of IT-equipment", *Proc. ERA Conf. on Quality and security of electrical supply*, February 26-27, 2001, Oxford, UK.

[5] J. Desmet, I. Sweertvaegher, G. Vanalme, K. Stockman and R. Belmans, "Analysis of the neutral conductor current in a three phase supplied network with non-linear single phase load's", *IEMDC/IEEE Conf.*, *MIT,* June 17-21, 2001, Cambridge, Massachusetts, USA, , electronic proc.

[6] J. Driesen, Th.Van Craenenbroek, D.Van Dommelen: "*The registration of harmonic power by analog and digital power meters*," IEEE Transactions on instrumentation and measurement, Vol.47, No.1, February 1998, pp.195-198.

[7] IEC internal document 77A/337/FDIS

[8] IEC61000-3-3, *"Electromagnetic compatibility (EMC) – Part 3-3: Limitation of voltage fluctuations and flicker in low voltage supply systems for equipment with rated current ≤ 16A".*

[9] A. Mansoor, W.M. Grady, A.H. Chowdhury, J.M. Samotyj, "An investingation of harmonics attenuation and diversity among distributed single phase power electronic loads", *IEEE Transactions on power delivery*, Vol 10, No 1, January 1995, pp 467-473.